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### 44-3.0 VERTICAL CURVES

#### 44-3.01 Crest Vertical Curves

A crest vertical curve is in the shape of a parabola. The basic equations for determining the minimum length of a crest vertical curve are as described below.

If the stopping sight distance is less than the vertical curve length ( $S < L$ ),

$$L = \frac{AS^2}{100 (\sqrt{2h_1} + \sqrt{2h_2})^2} = \frac{AS^2}{658} \quad (\text{Equation 44-3.1})$$

$$L = KA \quad (\text{Equation 44-3.2})$$

If the stopping sight distance is greater than or equal to the vertical curve length ( $S \geq L$ ),

$$L = 2S - \frac{658}{A} \quad (\text{Equation 44-3.3})$$

where:

$L$  = length of vertical curve, m

$A$  = algebraic difference between the two tangent grades, %

$S$  = stopping sight distance, m

$h_1$  = height of eye above road surface, m

$h_2$  = height of object above road surface, m

$K$  = horizontal distance needed to produce a 1% change in gradient

$L$  will depend upon  $A$  for the specific curve and upon the selected sight distance, height of eye, and height of object. The following discusses the selection of these values.

DESIGN SPEED (km/h)	ROUNDED SSD FOR DESIGN <sup>1</sup> (m)		CALCULATED K VALUES <sup>2</sup>		K VALUES ROUNDED FOR DESIGN	
	Des.	Min.	Des.	Min.	Des.	Min.
20	35	20	1.9	0.6	2	1
30	50	35	3.8	1.9	4	2
40	65	50	6.4	3.8	7	4
50	85	65	11.0	6.4	11	7
60	105	85	16.8	11.0	17	11
70	130	105	25.7	16.8	26	17
80	160	130	38.9	25.7	39	26
90	185	160	52.0	38.9	52	39
100	220	185	73.6	52.0	74	52
110	250	220	95.0	73.6	95	74
120	285	250	123.4	95.0	124	95

Notes:

- <sup>1</sup> *Stopping sight distances (SSD) are from Figure 42-1A.*
- <sup>2</sup> *K values are calculated using rounded values for design stopping sight distance, eye height of 1080 mm, and object height of 600 mm.*
3. *If curbs are present, and  $K > 51$ , proper pavement drainage should be ensured near the high point of the curve.*

**K VALUES FOR CREST VERTICAL CURVE**  
**(Stopping Sight Distance – Passenger Car)**

**Figure 44-3A**

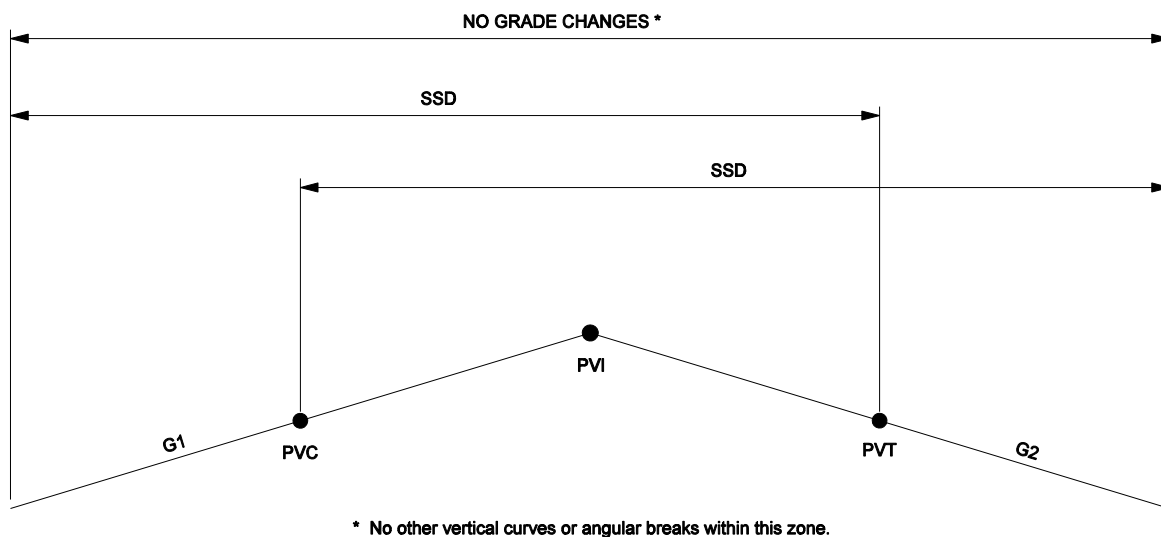
### 44-3.01(01) Stopping Sight Distance

The principal control in the design of a crest vertical curve is to ensure that, at a minimum, stopping sight distance (SSD) is available throughout the curve. Figure 44-3A, K Values for Crest Vertical Curve (Stopping Sight Distance – Passenger Car), provides K values for various design speeds where  $S < L$ . The following discusses the application of the K value.

1. Passenger Car. The K value is calculated by assuming  $h_1 = 1.08$  m,  $h_2 = 0.6$  m, and  $S = \text{SSD}$  in the basic equation for a crest vertical curve (Equation 44-3.1). The value represents the lowest acceptable sight distance on a facility. However, every reasonable effort should be made to provide a design in which the K value is greater than the value shown, where practical.

Where  $S \geq L$ , any of the following methods may be used to check the stopping sight distance.

- a. Using K Values. The K value provided is greater than or equal to the K value required and there are no changes to G1 or G2 in Figure 44-3A(1), Stopping Sight Distance Using K Values, Crest Vertical Curve.



STOPPING SIGHT DISTANCE CHECK USING K-VALUES,  
CREST VERTICAL CURVE

Figure 44-3A(1)

- b. Using Equation. Equation 44-3.3 shown above is only valid if there are no other vertical curves or angular breaks in the area shown in Figure 44-3A(1).
- c. Using the AASHTO *Policy on Geometric Design of Highways and Streets*.
- d. Checking Graphically. The eye should be placed at 1.08 m above the pavement and the height of the object at 0.6 m. The distance between the eye and the object that is unobstructed (by the road, backslope of a cut section, guardrail, etc.) is the stopping sight distance provided. It is necessary to check it in both directions for a 2-lane highway.

If the stopping sight distance provided exceeds that required (even though the K value provided is less than the K value required), the K value will be treated as a Level Three design exception item instead of Level One.

If the K value provided exceeds the K value required, it is not necessary to perform either the equation check or the graphical check even though  $S \geq L$ .

2. Truck. The higher eye height for a truck, 2.4 m, offsets the longer stopping distance required on a vertical curve. Therefore, the K value for truck stopping sight distance need not be checked.
3. Minimum Length. The minimum length of a crest vertical curve in meters should be  $0.6V$ , where  $V$  is the design speed in km/h, unless existing conditions make it impractical to use the minimum length criteria.

#### 44-3.01(02) Decision Sight Distance

It may sometimes be warranted to provide decision sight distance in the design of a crest vertical curve. Section 42-2.0 discusses candidate sites and provides design values for decision sight distance. These  $S$  values should be used in the basic equation for a crest vertical curve (Equation 44-3.1). In addition, the following will apply:

1. Height of Eye ( $h_I$ ). For a passenger car,  $h_I$  is 1.08 m.

Design Speed (km/h)	Avoidance Maneuver A (Stop on Rural Road)		Avoidance Maneuver B (Stop on Urban Road)		Avoidance Maneuver C (Speed/Path/Direction Change on Rural Road)		Avoidance Maneuver D (Speed/Path/Direction Change on Suburban Road)		Avoidance Maneuver E (Speed/Path/Direction Change on Urban Road)	
	DSD (m)	K Value	DSD (m)	K Value	DSD (m)	K Value	DSD (m)	K Value	DSD (m)	K Value
30	35	2	90	13	85	11	105	17	120	22
40	55	5	120	22	115	21	135	28	160	39
50	70	8	155	37	145	32	170	44	195	58
60	95	14	195	58	170	44	205	64	235	84
70	115	21	235	84	200	61	235	84	275	115
80	140	30	280	119	230	81	270	111	315	151
90	170	44	325	161	270	111	315	151	360	197
100	200	61	370	209	315	151	355	192	400	244
110	235	84	420	269	330	166	380	220	430	281
120	265	107	470	336	360	197	415	262	470	336

Notes:

1. See Section 42-2.0 for decision sight distances (DSD).
2. K values are calculated using the rounded value for design decision sight distance, eye height of 1080 mm, and object height of 600 mm.

$$K = \frac{DSD^2}{658}$$

3. If curbs are present and  $K > 51$ , proper pavement drainage should be ensured near the high point of the curve.

**K VALUES FOR CREST VERTICAL CURVE**  
(Decision Sight Distance – Passenger Car)

**Figure 44-3B**

2. Height of Object ( $h_2$ ). Decision sight distance, is often predicated upon the same principles as stopping sight distance; i.e., the driver needs sufficient distance to see a 0.6-m-height object.
3. Passenger Car. Figure 44-3B, K Values for Crest Vertical Curve (Decision Sight Distance – Passenger Car), provides the K values using the decision sight distances shown in Section 42-2.0.

#### **44-3.01(03) Drainage**

Drainage should be considered in the design of a crest vertical curve where a curbed section or concrete barriers are used. Drainage problems are minimized if the crest vertical curve is sharp enough so that a minimum longitudinal grade of at least 0.3% is reached at a point about 15 m from either side of the apex. To ensure that this objective is achieved, the length of the vertical curve should be based upon a K value of 51 or less. For a crest vertical curve in a curbed section where this K value is exceeded, the drainage design should be more carefully evaluated near the apex.

For an uncurbed roadway section, drainage should not be a problem at a crest vertical curve. However, it is desirable to provide a longitudinal gradient of at least 0.15% at points about 15 m on either side of the high point. To achieve this, K must equal 100 or less.

See Part IV for more information on drainage.

#### **44-3.02 Sag Vertical Curves**

A sag vertical curve is in the shape of a parabola. Typically, it is designed to allow the vehicular headlights to illuminate the roadway surface (i.e., height of object = 0 m) for a given distance  $S$ . A headlight height,  $h_3$ , of 0.6 m, and a 1-deg upward divergence of the light beam from the longitudinal axis of the vehicle are assumed.

##### **44-3.02(01) Stopping Sight Distance**

These assumptions yield the following basic equations for determining the minimum length of a sag vertical curve. If the stopping sight distance,  $S$ , is less than the vertical curve length,  $L$ ,

$$L = \frac{AS^2}{120 + 3.5S} \quad (\text{Equation 44-3.4})$$

If the stopping sight distance,  $S$ , is greater than or equal to the vertical curve length,  $L$ ,

$$L = 2S - \frac{120 + 3.5S}{A} \quad (\text{Equation 44-3.5})$$

where:

$L$  = length of vertical curve, m

$A$  = algebraic difference between the two tangent grades, %

$S$  = sight distance, m

$K$  = horizontal distance needed to produce a 1% change in gradient

The length of the sag vertical curve will depend upon  $A$  for the specific curve and upon the selected sight distance and headlight height. The following sections discuss the selection of these values.

The principal control in the design of a sag vertical curve is to ensure that, at a minimum, stopping sight distance (SSD) is available for headlight illumination throughout the curve. Figure 44-3C, K Values for Sag Vertical Curve (Stopping Sight Distance – Passenger Car), provides K values for various design speeds where  $S < L$ . The following discusses the application of the K value.

1. Passenger Car. The K value is calculated by assuming  $h_3 = 0.6$  m and  $S = \text{SSD}$  in the basic equation for a sag vertical curve (Equation 44-3.4). The value represents the lowest acceptable sight distance on a facility. However, every reasonable effort should be made to provide a design in which the K value is greater than the value shown, where practical.

Where the stopping sight distance is greater than or equal to the vertical curve length, any of the following methods may be used to check the stopping sight distance.

- a. Using K Values. The K value provided is greater than or equal to the K value required, and there are no changes to G1 or G2 as shown in Figure 44-3C(1), Stopping Sight Distance Using K Values, Sag Vertical Curve.
- b. Using Equation. Equation 44-3.5 shown above is only valid if there are no other vertical curves or angular breaks in the area shown in Figure 44-3C(1).
- c. Using the AASHTO *Policy on Geometric Design of Highways and Streets*.

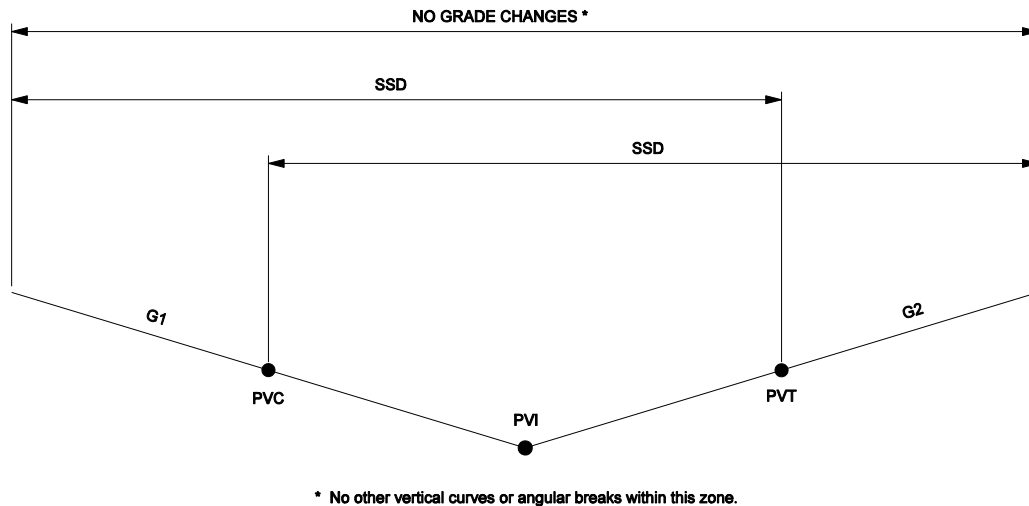
DESIGN SPEED (km/h)	ROUNDED SSD FOR DESIGN <sup>1</sup> (m)	CALCULATED K VALUES <sup>2</sup> $K = \frac{S^2}{(120 + 3.5S)}$	K VALUES ROUNDED FOR DESIGN
20	20	2.1	3
30	35	5.1	6
40	50	8.5	9
50	65	12.2	13
60	85	17.3	18
70	105	22.6	23
80	130	29.4	30
90	160	37.6	38
100	185	44.6	45
110	220	54.4	55
120	250	62.8	63

Notes:

1. *Stopping sight distances (SSD) are from Figure 42-1A.*
2. *K values calculated using rounded value for design stopping sight distance S and a headlight height of 600 mm.*
3. *If curbs are present and  $K > 51$ , proper drainage should be ensured near the low point of the curve.*

**K-VALUES FOR SAG VERTICAL CURVE  
(Stopping Sight Distance – Passenger Car)**

**Figure 44-3C**



**STOPPING SIGHT DISTANCE CHECK USING K-VALUES,  
SAG VERTICAL CURVE**

Figure 44-3C(1)

- d. **Checking Graphically.** The headlight should be placed at 0.6 m above the pavement and the height of the object at 0 m. The light beam is assumed at a 1-deg upward divergence from the longitudinal axis of the vehicle. The distance between the headlight and the object that is unobstructed (by the road, backslope of a cut section, guardrail, etc.) is the stopping sight distance provided. It is necessary to check it in both directions for a 2-lane highway.

If the stopping sight distance provided exceeds that required (even though the K value provided is less than the K value required), the K value will be treated as a Level Three design exception item instead of Level One.

2. **Truck.** The higher headlight height for a truck, 1.2 m, offsets the longer stopping distance required on a vertical curve. Therefore, the K value for truck stopping sight distance need not be checked.
3. **Minimum Length.** The minimum length of a sag vertical curve in meters should be  $0.6V$ , where V is the design speed in km/h, unless existing conditions make it impractical to use the minimum length criteria.

One exception to this minimum length may apply in a curbed section. If the sag is in a “sump,” the use of the minimum-length criteria may produce longitudinal slopes too flat to drain the stormwater without exceeding the criteria for the limits of ponding on the travel lane.

#### **44-3.02(02) Decision Sight Distance**

It may sometimes be warranted to provide decision sight distance in the design of a sag vertical curve. Section 42-2.0 discusses candidate sites and provides design values for decision sight distance. These  $S$  values should be used in the basic equation for a sag vertical curve (Equation 44-3.5). The height of headlights,  $h_3$ , is 0.6 m. Figure 44-3D, K Values for Sag Vertical Curve (Decision Sight Distance – Passenger Car), provides K values using decision sight distance.

#### **44-3.02(03) Drainage**

Drainage should be considered in the design of a sag vertical curve where a curbed section or concrete barriers are used. Drainage problems are minimized if the sag vertical curve is sharp enough so that both of the following criteria are met.

1. A minimum longitudinal grade of at least 0.3% is reached at a point about 15 m from either side of the low point.
2. There is at least a 100-mm elevation differential between the low point in the sag and the two points 15 m to either side of the low point.

To ensure that the first objective is achieved, the length of the vertical curve should be based upon a K value of 51 or less. For a sag vertical curve in a curbed section where this K value is exceeded, the drainage design should be more carefully evaluated near the low point. For example, it may be necessary to install flanking inlets on either side of the low point.

For an uncurbed roadway section, drainage should not be a problem at a sag vertical curve. However, it is desirable to provide a longitudinal gradient of at least 0.15% at points about 15 m on either side of the low point. To achieve this, K must equal 100 or less.

See Part IV for more information on drainage.

Design Speed (km/h)	Avoidance Maneuver A (Stop on Rural Road)		Avoidance Maneuver B (Stop on Urban Road)		Avoidance Maneuver C (Speed/Path/Direction Change on Rural Road)		Avoidance Maneuver D (Speed/Path/Direction Change on Suburban Road)		Avoidance Maneuver E (Speed/Path/Direction Change on Urban Road)	
	DSD (m)	K Value	DSD (m)	K Value	DSD (m)	K Value	DSD (m)	K Value	DSD (m)	K Value
30	35	6	90	19	85	18	105	23	120	27
40	55	10	120	27	115	26	135	31	160	38
50	70	14	155	37	145	34	170	41	195	48
60	95	20	195	48	170	41	205	51	235	59
70	115	26	235	59	200	49	235	59	275	70
80	140	33	280	72	230	58	270	69	315	82
90	170	41	325	84	270	69	315	82	360	94
100	200	49	370	97	315	82	355	93	400	106
110	235	59	420	111	330	86	380	100	430	114
120	265	68	470	126	360	94	415	110	470	126

Notes:

1. *K values are calculated using the rounded value for design decision sight distance and headlight height of 600 mm.*

$$K = \frac{DSD}{120 + 3.5S}$$

2. *If curbs are present and  $K > 51$ , proper pavement drainage should be ensured near the low point of the curve.*

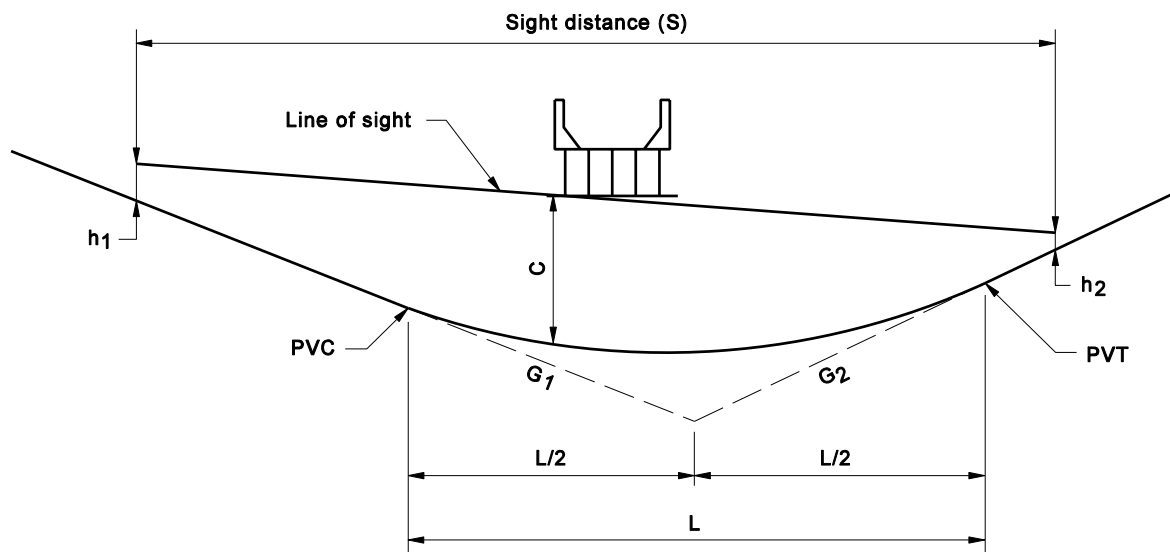
**K VALUES FOR SAG VERTICAL CURVE  
(Decision Sight Distance – Passenger Car)**

**Figure 44-3D**

**44-3.02(04) Sight Distance at Undercrossing**

Sight distance on a highway through a grade separation should be at least as long as the minimum stopping sight distance and preferably longer. Design of the vertical alignment is the same as at any other point on the highway except where a sag vertical curve underpasses a structure, as shown in Figure 44-3D(1), Sight Distance at Undercrossing. While not a frequent problem, the structure fascia may cut the line of sight and limit the sight distance to less than that otherwise attainable. It is generally practical to provide the minimum length of sag vertical curve at a grade separation structure. Even where the recommended grades are exceeded, the sight distance should not need to be reduced below the minimum values for stopping sight distance.

The available sight distance should sometimes be checked at an undercrossing, such as at a two-lane undercrossing without ramps, where it would be desirable to provide passing sight distance. Such checks are best made graphically on the profile, but may be performed through computations.

**SIGHT DISTANCE AT UNDERCROSSING****Figure 44-3D(1)**

The general equations for sag vertical curve length at an undercrossing are as follows:

1. Sight distance,  $S$ , greater than vertical curve length,  $L$ ,

$$L = 2S - \left\{ \frac{800[C - 0.5(h_1 + h_2)]}{A} \right\} \quad (\text{Equation 44-3.6})$$

2. Sight distance,  $S$ , less than or equal to vertical curve length,  $L$ ,

$$L = \frac{AS^2}{800[C - 0.5(h_1 + h_2)]} \quad (\text{Equation 44-3.7})$$

For both equations, where:

$L$  = length of vertical curve, m

$S$  = sight distance, m

$A$  = algebraic difference in grades, %

$C$  = vertical clearance, m

$h_1$  = height of eye, m

$h_2$  = height of object, m

Using an eye height of 2.4 m for a truck driver and an object height of 0.6 m for the taillights of a vehicle, the following equation can be derived.

3. Sight distance,  $S$ , greater than vertical curve length,  $L$ ,

$$L = 2S - \frac{800(C - 1.5)}{A} \quad (\text{Equation 44-3.8})$$

4. Sight distance,  $S$ , less than or equal to vertical curve length,  $L$ ,

$$L = \frac{AS^2}{800(C - 1.5)} \quad (\text{Equation 44-3.9})$$

### 44-3.03 Vertical Curve Computations

The following will apply to the mathematical design of a vertical curve.

1. Definitions. Figure 44-3E, Vertical Curve Definitions, presents the common terms and definitions used in vertical curve computations.
2. Measurements. All measurements for a vertical curve are made on the horizontal or vertical plane, not along the profile grade. With the simple parabolic curve, the vertical offsets from the tangent vary as the square of the horizontal distance from the PVC or PVT. Elevations along the curve are calculated as proportions of the vertical offset at the point of vertical intersection (PVI). The necessary formulas for computing the vertical curve are shown in Figure 44-3F, Symmetrical Vertical Curve Equations. Figure 44-3G, Vertical Curve Computations (Example 44-3.1), provides an example of how to use these formulas.
3. Unsymmetrical Vertical Curve. Occasionally it is necessary to use an unsymmetrical vertical curve to obtain clearance on a structure or to satisfy some other design feature. This curve is similar to the parabolic vertical curve, except the curve does not vary symmetrically about the PVI. The necessary formulas for computing the unsymmetrical vertical curve are shown in Figure 44-3H, Unsymmetrical Vertical Curve Equations.
4. Vertical Curve Through Fixed Point. A vertical curve often must be designed to pass through an established point. For example, it may be necessary to tie into an existing transverse road or to clear existing structures. See Figure 44-3 I, Vertical Curve Computations. Figure 44-3J, Vertical Curve Computations (Example 44-3.2), illustrates an example on how to use these formulas.